Production of W and Z in ATLAS

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From 2009, proton-proton collisions will be produced at the Large Hadron Collider. The nominal beam energy and luminosity are respectively 7 TeV and 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The ATLAS detector is a general-purpose detector which will record data from these collisions. In this note, strategies for the measurements of the electronic and muonic decays of W and Z bosons are presented and prospects for the expected precision with 50 pb^{-1} of data are reported.

1. Introduction

W and Z bosons will be abundantly produced at the Large Hadron Collider (LHC) and electron and muon decay channels will provide clean samples. The production mechanisms of W and Z bosons are first briefly introduced. Then ATLAS [1] analysis strategies for the W and Z inclusive cross-section measurements are presented, emphasizing the early running period. Results from simulated data are given. Finally the results that will be achieved with a higher integrated luminosity ($\sim$ 1 fb^{-1}) are discussed. All the presented results are obtained from simulations for a center-of-mass energy of 14 TeV.

2. W and Z production mechanisms

In proton-proton collisions at LHC, W and Z bosons are mainly produced by valence-sea quarks interactions. The sea-sea quark contribution is at a level of 20% for W and 10% for Z, a much higher level than at Tevatron, see Ref. [2] for details. Given the quark composition of the proton, the W^+ production cross-section is 1.4 times the W^- production cross-section. The high beam energy and the large rapidity coverage of the ATLAS detector will allow to cover a very large kinematics area in the $x - Q^2$ plane (see Fig. 1). W and Z processes (in particular the forward $Z \to ee$ events) will constraint the parton density functions (PDFs) at low x ($\sim 10^{-4}$) for Q^2 equal to 10^4 GeV^2.

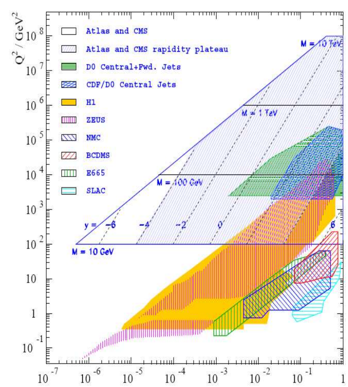

Figure 1. Kinematic coverage of LHC experiments and of other relevant experiments.

3. Inclusive cross-sections measurements

Experimentally, the cross-section of a given process is measured using the following formula:

$$\sigma = \frac{N - B}{A\epsilon_e\epsilon_t \int Ldt}$$

where N is the number of selected events, B the number of background events, A the geometric and kinematic acceptance, ϵ_e the offline electron reconstruction efficiency, ϵ_t the trigger efficiency with respect to offline and $\int Ldt$ the integrated luminosity.

The jet activity at LHC is so high that only leptonic decays can be selected with sufficient purity. Prospects for the W and Z inclusive cross-sections measurements in the electronic and muonic channels for the first 50 pb^{-1} of data have been extensively studied. The determination of the cross-section components are summarized in the next sections. Reference [3] provides further details. In all the presented analyses, the data have been produced with the Pythia event generator [4] and the full simulation of the detector has been done using Geant4 [5].

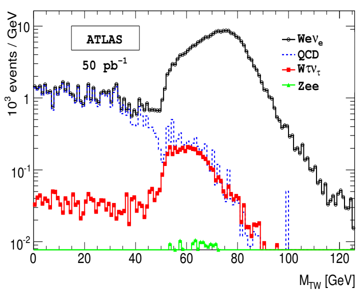

Figure 2. W transverse mass distribution in the electron channel for signal and backgrounds. All histograms are cumulative. The expected numbers of events are normalized to 50 pb^{-1}.

3.1. Selections

At the start-up of the data-taking, the detector will not be fully understood: therefore the defined selections result from the search of a compromise between the simplicity required for the first phase, the signal selection efficiency and the background rejection. They are mainly based on single lepton triggers (both for W and Z) and the selection of high transverse momentum leptons (for the neutrino, a cut on the transverse missing energy ($\not\!\!E_T$) is applied). For the leptons identification, cuts-based methods are applied. Distributions for signal and background resulting from the defined selections in the $W \to e\nu_e$ and $Z \to \mu\mu$ channels are shown respectively in Fig. 2 and Fig. 3.

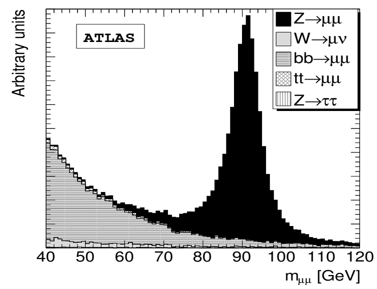

Figure 3. Z invariant mass distribution in the muon channel for signal and backgrounds. All histograms are cumulative. The expected numbers of events are normalized to 50 pb^{-1}.

3.2. Background contribution

Backgrounds can be classified in two categories: electroweak backgrounds (e.g. $Z \to ee$ for $W \to e\nu_e$) and QCD background (corresponding to events with jets faking leptons or with non isolated leptons inside jets). Electroweak backgrounds are well known theoretically and can be safely estimated from MC simulations. On the contrary, QCD background is poorly known because of non perturbative effects and magnitudes are at best known within a factor of 2. Therefore it is necessary to develop tools to monitor these backgrounds from data. A promising idea is to use a control sample (almost signal free) selected applying orthogonal cuts and to parametrize the background in this sample. The shape is then used to substract the correct number of background events in the signal sample.
For W events, the $\not\!\!E_T$ shape for background can be determined on a pure jets sample selected applying a photon trigger and the same calorimetric identification electron cuts (an invariant mass cut is also applied to the remove the $Z \to ee$ background, relatively high without the $\not\!\!E_T$ cut).
For Z events, the background shape can be determined on a sample selected requiring two same sign leptons.

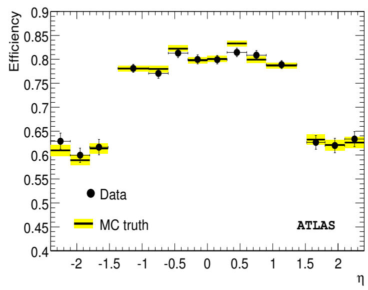

Figure 4. η distribution of the combined trigger plus electron selection efficiency. Monte-Carlo and tag-and-probe results for $Z \to ee$ events are represented. Statistical uncertainties are given for 50 pb^{-1}.

3.3. Selection efficiencies

Trigger and offline reconstruction efficiencies have to be estimated from data. The tag-and-probe method has been applied. This method has been widely and successfully used in Tevatron's experiments [6]). In the case of the Z boson, the principle is the following: in a sample of $Z \to ll$ events such that the first lepton passes the full selection (=tag lepton), the second lepton satisfies the geometric and kinematic requirements (=probe lepton) and the di-lepton invariant mass is close to the Z mass, the measured efficiency is the fraction of events in which the probe lepton satisfies the tested criterion. It has been shown that this method does not introduce any bias in both (electron and muon) channels: Figure 4 shows the agreement over the whole eta range between the Monte-Carlo (MC) and the tag-and-probe results for the electron channel. An advantage of the method is that it can be applied in an iterative way to control the efficiency of each cut. A second advantage is that the uncertainty decreases with the integrated luminosity: for 50 pb^{-1}, the uncertainty on the combined efficiency is of the order of 3% and for 1 fb^{-1}, it is below 1%.

3.4. Acceptance

The acceptance is the probability that given e.g. a boson decaying into two electrons, both electrons satisfy the geometric and kinematic requirements at detector level. The detector simulation does play a role for the acceptance computation. But the results reported here have been obtained from generator-level analyses: this is often the case in such analyses because the statistics needed to reach the required precision (below 1%) prevents from simulating a high number of samples corresponding to different MC generators configurations. A preliminary estimation of the impact of some generators ingredients (the Initial State Radiation, the intrinsic k_{T} for the incoming partons, the Underlying Event, the matrix element corrections applied to the parton shower and the electroweak correction using PHOTOS [7]) has been done, switching alternatively on and off the corresponding effects and comparing Pythia and Herwig [8] events. The impact of PDFs has been studied varying the eigenvectors of the CTEQ6.5 set. This has led to a relative acceptance uncertainty of 2% for both W and Z, the major contribution coming from the PDFs in both cases. It has to be noted that the impact of the QCD higher order corrections is not included in these results.

3.5. Analysis results

One of the main aims of these analyses on simulated data is to assess the uncertainties with which the cross-sections can be measured; summary results for the cross-sections and their uncertainties are given for the four channels in Table 3.5. The cross-sections are normalized to the QCD next-and-next-to-leading-order predictions provided by the FEWZ program [9]. The luminosity uncertainty, expected to be at a $10 - 20\%$ level during the first year, is not included. These results show that already with 50 pb^{-1}, the total measurement uncertainty is dominated by the systematic uncertainty. With more statistics, the acceptance will become the dominant term and will limit the precision of the measurement.

Process	$\sigma \pm$ stat. $\pm$ syst. (pb)
$W \to e\nu$	$20520 \pm 40 \pm 1060$
$W \to \mu\nu$	$20530 \pm 40 \pm 630$
$Z \to ee$	$2016 \pm 16 \pm 83$
$Z \to \mu\mu$	$2016 \pm 16 \pm 76$

Table 1
Measured cross-sections and their uncertainties. The statistical uncertainty is given for 50 pb^{-1}, the systematic uncertainty includes theoretical and experimental effects, but not the luminosity uncertainty.

4. Beyond first data

Three kinds of measurements which require a precise control of W and Z production are given in this section.

The absolute luminosity will be poorly known at the beginning: W and Z cross-sections measurements will probably be used to get the integrated luminosity of data samples, thus allowing to normalize the cross-sections of other processes. A $2-3\%$ level should be ultimately reachable.

Constraints on PDFs can be set as soon as experimental uncertainties are under control at the required level. Looking for example at the rapidity of the W decay leptons, it has been shown in Ref. [10] that with only 250 pb^{-1}, the uncertainties on some parameters are significantly reduced (up to 40% for the gluon paramater at low x). This result has been obtained assuming that experimental uncertainties are under control at a 5% level.

A good control of the inclusive W and Z production is an unavoidable prerequisite for the W/Z+jets final state measurement, which is important for Standard Model (SM) and Beyond Standard Model (BSM) searches. These processes are the main background for the SM Higgs produced by vector boson fusion and for many Supersymetry searches. Finally, it is important to precisely control the Drell-Yan production over a large range of the di-lepton invariant mass since at high mass, this process is sensitive to new heavy resonances, present in several BSM scenarios.

5. Conclusion

The analysis methods developed for the inclusive W and Z cross-section measurements in ATLAS have been presented in this note: they should be seen as a starting point which will be adapted as soon as first data arrive. However, analyses have been carried out in a realistic environment (including the trigger, a full simulation of the detector and data-driven methods) and it has been shown that, given the expected performances of the detector, robust methods should allow to reach measurements at a 5% level of precision or better for 50 pb^{-1} of data, apart from the luminosity uncertainty.

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